Jan. 15, 1963 G. McNEIR ETAL 3,074,042

LOW-INDUCTANCE RESISTOR

Filed Nov. 25, 1959

2 Sheets-Sheet 1

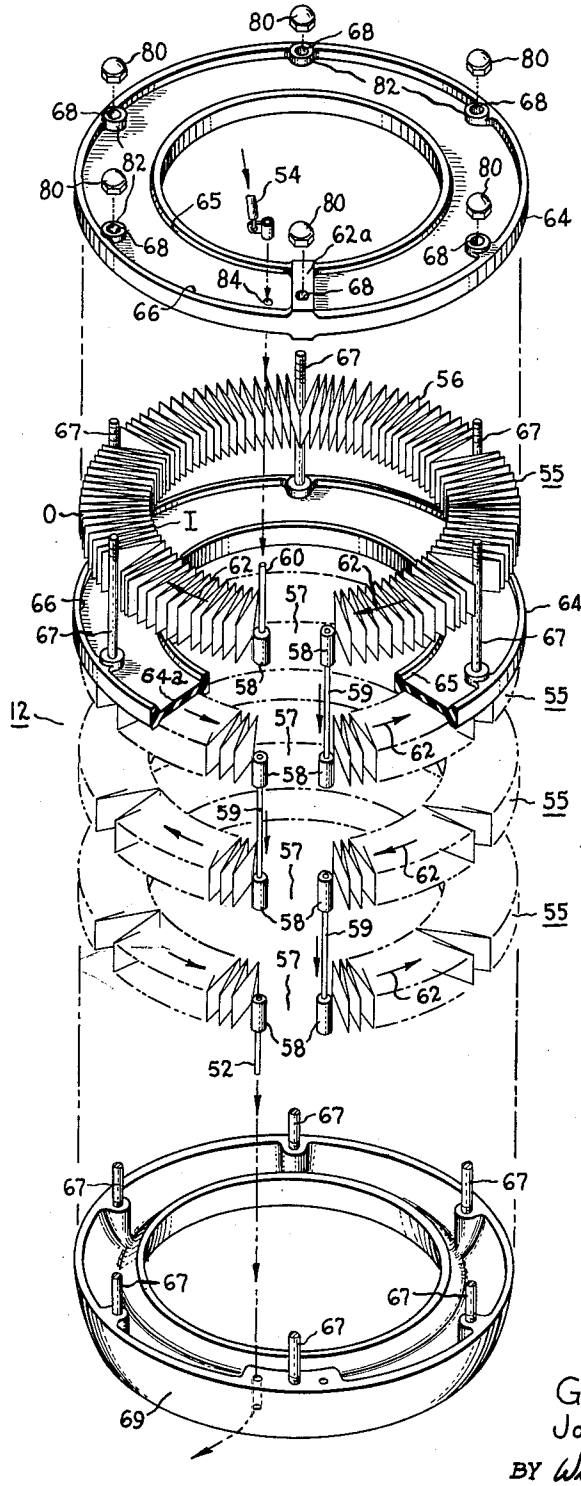


Fig. 2

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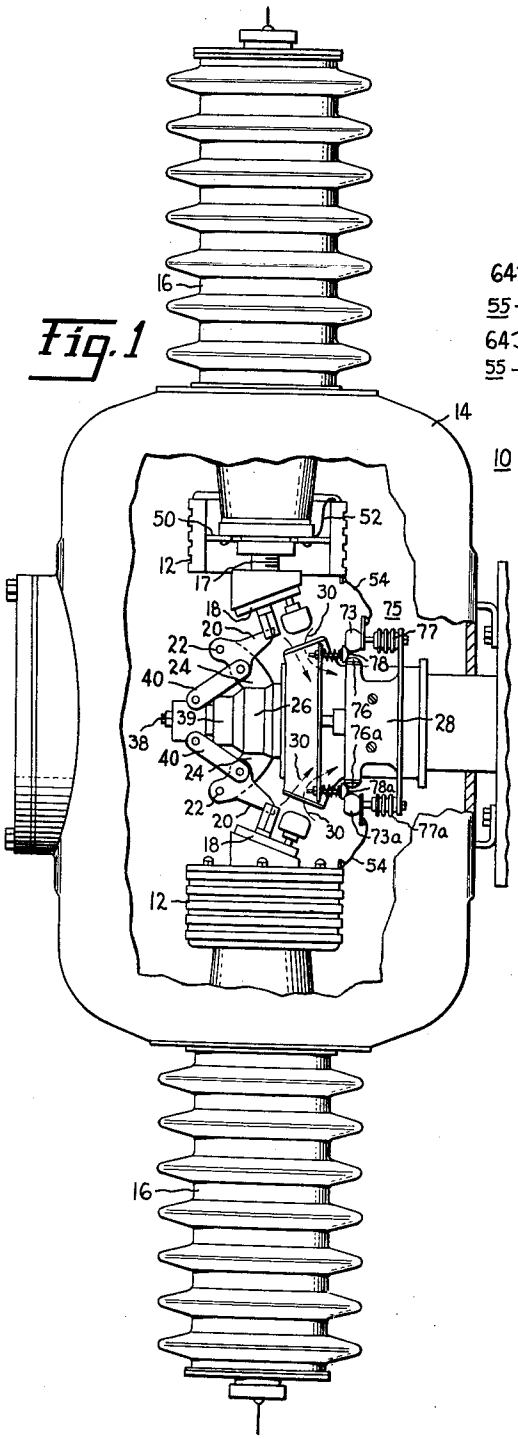
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2 Sheets-Sheet 2

Fig. 1



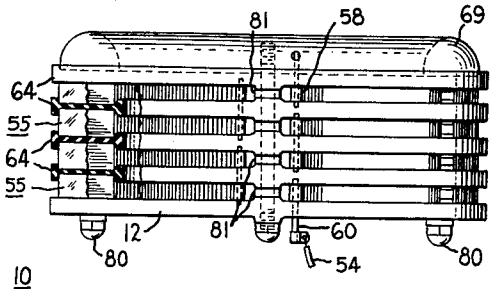


Fig. 4

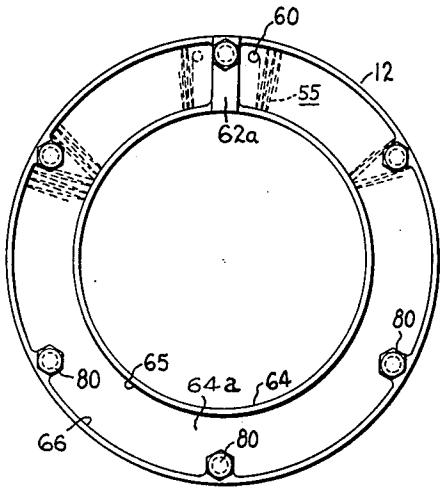


Fig. 3

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LOW-INDUCTANCE RESISTOR

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8 Claims. (Cl. 338—280)

This invention relates to a low-inductance resistor and, more particularly, to a compact, low-inductance resistor which is especially suited for high voltage applications.

It has been recognized heretofore that the inductance of a resistor element can be held to a relatively low value by forming the resistor element of a zig-zag or serpentine configuration. But prior designs of this nature of which we are aware have either consumed an excessive amount of space per unit of resistance, have been incapable of withstanding the high voltages with which we are concerned, or have had an excessive amount of inductance per unit of resistance. Efforts to improve the resistor in any one of these respects without producing excessive temperature rises during resistor operation have usually resulted in impairing the characteristics of the resistor in one or both of the other respects.

Accordingly, an object of our invention is to provide a resistor which has an extremely low inductance per unit of resistance and which is exceptionally compace in comparison to prior resistors of corresponding resistance and voltage rating.

Another object is to construct the resistor in such a manner that it can be quickly and easily assembled utilizing sets of identical components. By limiting the number of different types of components required, manufacturing costs and component inventories can be reduced and the possibility of errors in the assembly operation is lessened.

In carrying out our invention in one form, we construct our low-inductance resistor of a plurality of annular resistor units, each of which comprises a conductive ribbon extending circumferentially about the unit between opposite sides of an electrical discontinuity in the unit. Each of the conductive ribbons comprises closely-spaced series-connected segments extending alternately between the outer periphery and the inner periphery of the annular unit. The adjacent faces of these segments are covered with insulating means that requires current traversing the ribbon at any given instant to flow in generally opposite directions through adjacent segments of each ribbon. The annular resistor units are mounted in superimposed collinear relationship with the regions of discontinuity circumferentially aligned. Means are provided for electrically interconnecting the resistor units in series-circuit relationship in such a manner that at any given instant current traversing the resistor flows in opposite circumferential directions through adjacent resistor units.

For a better understanding of our invention, reference may be had to the following description taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a side elevational view, partly in section, showing an air blast circuit breaker comprising resistors embodying one form of our invention.

FIG. 2 is an exploded view of the lower resistor of FIG. 1 with certain elements of the resistor being omitted for the sake of clarity.

FIG. 3 is an end view of the resistor of FIG. 2.

FIG. 4 is a side view, partly in section, of the resistor of FIG. 3.

Referring now to FIG. 1, there is shown an air blast circuit interrupter 10 including two low-inductance resistors 12 constructed in accordance with one form of our invention. Apart from the resistors, the details of the interrupter form no part of the present invention and

will therefore be only briefly described. For a more detailed description of the interrupter, reference may be had to application Serial No. 697,878—Oppel, filed November 21, 1957, now Patent No. 2,911,546, and assigned to the assignee of the present invention.

Generally speaking, the interrupter comprises a metallic tank 14 filled with pressurized arc-extinguishing gas and a pair of high voltage terminal bushings 16 projecting into the tank from diametrically-opposed points. Each of these bushings includes a conductive stud 17 extending therethrough and carrying a stationary contact assembly 18 at its inner end. Cooperating with each stationary contact assembly 18 is a movable contact 20 pivotally mounted on a stationary pivot 22. These pivots are supported upon stationary brackets 24 which are integral with one end of a stationary operating cylinder 26. Suitable means (not shown) are provided for transferring current between the movable contact 20 and the brackets 24, so that the brackets 24 together with the cylinder 26 form a conductive path electrically interconnecting the two movable contacts 20.

Cylinder 26 at its right-hand end, is suitable supported from a generally cylindrical housing 28, which, in turn, is suitably secured at its right hand end to the metallic casing 14.

When the movable contacts 20 are separated from their respective stationary contacts 18, a circuit interrupting arc is established between each pair of contacts, and such arcs 18 are extinguished by reliance upon a blast of gas flowing through the arcing region. This blast of gas flows through the arcing region in the general direction of the arrows 30, through suitable nozzle structure in the housing 28, and thence to atmosphere. A suitable blast valve (not shown) is disposed within the tubular housing 28 to control the flow of the gas blast, permitting such blast only during the circuit-interrupting interval.

For operating the blast valve and the movable contacts 20, a combined operating mechanism, preferably of the fluid-actuated type shown in Beatty Patent 2,783,338, assigned to the assignee of the present invention, is provided within the cylinders 26 and 28. The details of this operating mechanism form no part of the present invention and, hence, such details are not shown in the present application. An adequate understanding of the present invention may be had if it is understood that the operating mechanism acts during an opening operation to drive a piston rod shown at 38 to the left. The piston rod 38 is coupled to the contacts 20 through a cross-head 39 and pivotally-connected links 40, and, hence, such movement of the piston rod serves to drive the contacts open.

Each pair of the main contacts is shunted by the cylindrical resistor 12 embodying one form of our invention. This resistor 12 is supported from the conductive stud 16 by means of radially extending insulating supports 50 bolted to a portion of the bushing. The upper terminal of the upper resistor 12 is electrically connected to the stud 17 by means of a conductor shown schematically at 52, whereas the lower terminal of the resistor is electrically connected by means of a conductor 54 to an electrode 73 of a resistor switch 75.

The resistor switch 75, which is described and claimed in the aforementioned Oppel application, comprises, in addition to the electrode 73, a second electrode 76 spaced from electrode 73 and coacting with the electrode 73 to form an interrupting gap between the two electrodes. The electrode 73 is supported on the central housing 28 by an insulator 77 which is capable of electrically isolating the electrode 73 from the housing 28 when the resistor switch is open. The electrode 76 is also supported on the housing 28 but is electrically connected to the housing. Electrically bridging the two stationary electrodes 73 and 76 is a movable electrode 78, which in its closed posi-

tion of FIG. 1 butts against the two stationary electrodes. Thus, it will be seen that the resistor 12 is connected in shunt with the upper contacts 18, 20 by means of a circuit which extends through the parts 52, 12, 54, 73, 78, 76, and 28. As will be apparent from FIG. 1, the lower main contacts 18, 20 are shunted by a similar circuit. Since the parts forming this lower shunt circuit are substantially identical to those forming the upper circuit, corresponding lower parts have been assigned corresponding reference numerals followed by the suffix "*a*."

The resistor switch 75 is operated to an open position shortly after the main contacts part by suitable operating means, such as claimed in the aforesaid Oppel application, controlled from the cross-head 39. Prior to opening of the resistor switch 75, the resistors 12 remain connected across the separated main contacts, and during this interval serve their intended function of lowering the rate at which the usual recovery voltage transient builds up across the space between the contacts following a current zero. When enough separation of the main contacts has taken place to assure successful interruption, the resistor switch 75 is opened to interrupt the flow of current through the resistors, thereby completing the circuit-interrupting operation.

For each of the resistors 12 to effectively perform in the intended manner, it is important that its inductance be extremely low. It is also necessary that it be capable of withstanding the entire open-circuit voltage between a set of open contacts 18, 20 which in one typical interrupter is in excess of 69,000 volts. It is also necessary that each of the resistors be of a highly compact construction inasmuch as only a limited space is available inside the tank 14 for the resistors, particularly since adequate clearances must be maintained about the exterior of the resistor to preclude electrical breakdown from the resistor to adjacent lower voltage parts.

The manner in which our cylindrical resistor 12 satisfies these requirements will become apparent as the following detailed description of the resistor proceeds. Referring first to the exploded view of FIG. 2, it will be noted that the cylindrical resistor 12 contains a centrally-disposed open passageway extending longitudinally thereof and comprises a series of annular resistor units 55 surrounding this centrally-disposed passageway in collinear relationship. Each of the annular resistor units comprises a conductive ribbon 56 extending circumferentially about the unit between opposite sides of an electrical discontinuity 57. Each of the conductive ribbons 56 comprises closely-spaced, series-connected segments, adjacent ones of which extend alternately between the outer periphery O and the inner periphery I of each annular resistor unit 55. As will be apparent from FIGS. 2 and 3, these segments extend in a predominantly radial direction with respect to the cylindrical resistor 12. The junction between adjacent segments is of a sharp angle configuration rather than a curved configuration, and this enables the adjacent segments to be disposed more closely adjacent each other than would be the case if the junctions were of a curved configuration. In addition, the fact that each segment is of ribbon form rather than of a circular or square cross-section, facilitates obtaining the desired very close spacing of the adjacent segments. This follows from the fact that it is easier to fold a ribbon at a sharp angle on itself than it is to so fold a round or square wire of equal cross-sectional area.

As will be apparent from FIGS. 2 and 4, the inner periphery I of each resistor unit borders and communicates with the centrally-disposed passageway through the cylindrical resistor 12, thus enabling this region of each resistor unit to be cooled by the gas present in this passageway.

Each of the ribbons 56 is covered by a thin coating of insulation, preferably several mils in thickness, and such insulation requires current traversing the ribbon 56 to flow through the length of each segment from one periphery of the resistor unit 55 to the other periphery. The current then flows back to the one periphery through the length of the adjacent segment, then back to the other periphery through the next segment, and so on. In other words, current traversing the ribbon at any given instant flows in generally opposite directions through adjacent segments.

The inductance of a given length of conductor folded back and forth on itself bears a direct relationship to the distance between the effective current paths through adjacent folds or segments. The smaller is this distance, the lower is the inductance of this given length of conductor. The use of a ribbon form, such as that of the element 56, contributes toward minimizing this distance not only because a ribbon lends itself to being sharply folded on itself but also because the center lines of ribbon segments can be inherently closer together than those of round or square segments of equal cross-sectional area due to the extreme flattened configuration of a ribbon. Because of this flattened configuration, the distance between the center line and the outer surface of the ribbon is relatively small, and, thus, the outer surface interferes less with close positioning of the center lines of adjacent segments.

For connecting the annular units 55 in series-circuit relationship, each ribbon is provided with a pair of tubes welded to its respective opposite ends. The tubes of each unit are disposed in aligned relationship with those of the other units, and conductive pins 59 are tightly fitted into alternate pairs of aligned tubes, as shown in FIG. 2. As a result, current entering the resistor through the top terminal 60 of the resistor flows through the upper annular unit 55 in a generally clockwise direction, through the next lower unit 55 in a counterclockwise direction, through the next lower unit 55 in a clockwise direction, and through the lowermost unit 55 in a counterclockwise direction, all as indicated by the arrows 62 of FIG. 2. By forcing the current to flow through adjacent annular units 55 in opposite circumferential directions, the inductance of one annular unit tends to cancel out the inductance of the adjacent annular unit. By having an even number of annular units, the inductance of each unit is effectively cancelled out.

The conductive pins 59 which interconnect the adjacent annular resistor unit 55 are preferably of a tubular longitudinally-split construction. When such pins are pressed into the tubes 58 at the ends of the resistor units, the pins 59 are circumferentially compressed. The resilience of the tubular pin forces the walls of the pin into firm current-carrying engagement with the inner surfaces of the outer tubes 58.

The electrical discontinuity in each annular unit 55 not only forces the current through adjacent units to flow in opposite circumferential directions but also serves to preclude any electrical breakdown between opposite ends of each ribbon. In a four unit resistor such as shown, approximately one-fourth of the total voltage is applied between opposite ends of each ribbon, and, accordingly, the discontinuity must have substantial dielectric strength to preclude a breakdown between these ends. Because our ribbon configuration allows the segments of the resistor unit to be located very close together and thus lends itself to efficient utilization of its available space, i.e., has a high space factor, there is sufficient space remaining at the ends of the resistor element to provide the required dielectric strength between these ends.

The required dielectric strength between adjacent annular resistor units is provided by means of a series of annular insulating discs 64 disposed between the respective adjacent units. Each of these discs includes a web portion 64*a* and a pair of annular flanges 65 and 66 at the opposite peripheries of the disc. The purpose of the flanges is to provide for increased creepage lengths as compared to the creepage lengths that would be present without the flanges and also to provide positive position-

ing means for confining the segments of the ribbon against any radial displacement past either periphery of the disc. The fact that the web **64***a* of each disc is of a lesser thickness, considered along the resistor length, than the end portions of the disc desirably contributes to a reduction in the overall length of the resistor.

For clamping the resistor units **55** together with their electrical discontinuities **57** in alignment and with the insulating spacers **64** sandwiched between the resistor units **55**, a series of longitudinally-extending, circumferentially-spaced tension members in the form of studs **67** of insulating material are provided. These studs extend through holes **68** provided at circumferentially-spaced points near the outer periphery of each insulating disc and are positioned between sets of adjacent segments of each resistor unit. The studs **67** are received at one end in suitably threaded holes provided in an electrostatic shield **69** serving as an end cap for the resistor and are received at their other end in suitably threaded nuts **80**. Tightening of the nuts **80** clamps the entire unit together, with the clamping pressure on the resistor units being limited by suitable tubular spacers, such as **81**, provided about each of the studs between adjacent insulating discs **64**. When so assembled, each of the resistor units is located about substantially its entire circumference in a single plane generally perpendicular to the longitudinal axis of the resistor, as will be apparent from FIGS. 2 and 4.

Locating the studs **67** near the outer periphery of each resistor unit **55** is desirable inasmuch as such location enables the studs to consume none of the space necessary for the resistor element **56**. This follows from the fact that the maximum number of segments that can be included in any given resistor unit **55** is determined by the inner peripheral dimension of the unit. The outer peripheral dimension being larger than the inner peripheral dimension, space is available near the outer periphery which could not readily be used for the resistor element. By using this outer peripheral space, instead of some space located at the inner periphery, it is unnecessary to lessen the number of segments per ribbon to provide space for the studs. It is also unnecessary to perforate the ribbon to accommodate the studs in view of the outer peripheral space that is available for receiving the studs. Preferably, the regions on both faces of the spacers **64** around each stud-receiving hole **68** are embossed, as at **82**, so as to provide for greater creepage distances between the adjacent resistor units. On both the top and bottom surface of each spacer **64**, the embossment **62***a* around the stud-receiving hole **68** that is located in the region of the discontinuity **57** extends continuously from one periphery of the spacer to the other periphery so as to insure complete separation between the opposite ends of each annular resistor unit **55** and so as to provide adequate creepage distance between these ends.

All of the spacers between adjacent resistor units are preferably identical to the spacer **64** shown at the top of FIG. 2. Also the bottom surface of each spacer is preferably identical in configuration to the top surface depicted in FIG. 2. Although the pins **59** and **60** extending through each spacer **64** are not aligned, this is accommodated for byinverting the spacers between alternate sets of resistor units. For example, in the top spacer **64** of FIG. 2 the hole **84** for receiving the pin **60** is shown to the left of the front stud **67**. When an identical spacer is inverted, this hole **84** would be to the right of the stud **67** and in a position to receive the pin **59** between the top and the next lower resistor unit. To adapt the spacer **64** for inverted use in this manner, all of the pins **59** and **60** are located at an equal distance from the longitudinal axis of the resistor unit and are equally spaced in a circumferential direction from the adjacent stud **67**. In other words, these pins are symmetrically located with respect to a diametrical axis of the resistor. The fact that the electrical discontinuities in each resistor unit disposed between the pins **59** are aligned also contributes to the ability of identical spacers to be used in inverted relationship.

Each of the conductive pins **59** connects a set of adjacent ends of adjacent resistor units and, hence, these ends are at approximately the same voltage. But between the other set of adjacent ends of adjacent resistor units, the voltage drop across two of the resistor units is developed. The insulating disc **64** is imperforate at this point inasmuch as the single hole **84** is utilized for the connecting pin **59**, and this solid imperforate barrier of insulation effectively precludes a breakdown between those two adjacent ends which are at widely different voltages.

Another feature that enables the spacers to be disposed in inverted relationship between adjacent resistor units is the fact that the studs **67**, being equally spaced apart circumferentially and being the same distance from the longitudinal axis of the resistor, are symmetrically located with respect to a diametrical axis of the resistor. Accordingly, when the spacers **64** are inverted, holes **68** are available to receive the studs.

The fact that each of the spacers and each of the resistor units are identical contributes to reduced manufacturing costs inasmuch as this identity makes it unnecessary to provide the different tools or manufacturing procedures that would be required to manufacture different parts. The identity of the parts also lessens the possibility of erroneously assembling parts through possible substitution of one partf or another.

While we have shown and described a particular embodiment of our invention, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from our invention in its broader aspects and we, therefore, intend in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of our invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. A low inductance resistor of cylindrical configuration having a centrally-disposed open passageway extending longitudinally of said resistor, said resistor comprising a plurality of annular resistor units surrounding said centrally-disposed open passageway, each unit comprising a conductive ribbon extending circumferentially about the unit, said ribbon having a pair of ends circumferentially-spaced apart to define an electrical discontinuity in each unit between the ends of said ribbon, each of said conductive ribbons being disposed about substantially its entire circumference in a single plane extending transversely of said resistor and comprising closely-spaced series-connected segments extending alternately between the outer periphery and the inner periphery of the annular unit in a predominantly radial direction with respect to said cylindrical resistor, insulating means between the adjacent faces of said segments for requiring current traversing said ribbon at any given instant to flow in generally opposite directions through adjacent segments of each ribbon, the inner periphery of said annular units bordering said centrally-disposed open passageway and communicating therewith, annular discs of insulating material disposed between said resistor units, means for mounting said annular resistor units and said annular insulating discs in superimposed generally colinear relationship with said regions of discontinuity being circumferentially aligned, and means electrically interconnecting said units in series circuit relationship in such a manner that at any given instant current traversing said resistor flows in opposite circumferental directions through adjacent annular resistor units.

2. The resistor of claim 1 in which the junction between adjacent segments of each ribbon is of a sharp angle configuration.

3. The resistor of claim 1 in which said electrical connecting means between said resistor units comprises metallic tubes attached to the ends of adjacent ribbons, a

pair of tubes of adjacent ribbons being disposed in alignment with each other, and a metallic pin extending generally axially of said resistor and tightly fitted into said aligned tubes for electrically interconnecting said tubes.

4. The resistor of claim 1 in which said electrical connecting means between adjacent resistor units comprises metallic tubes attached to the opposite ends of said ribbons on opposite sides of the electrical discontinuity in each resistor unit, one of the tubes of each resistor unit being aligned with one of the tubes of the remaining resistor units and the other tube of each resistor unit being aligned with the other tubes of the remaining resistor units, and metallic pins extending generally axially of said resistor and tightly fitted into alternate sets of aligned tubes for electrically interconnecting said alternate sets of tubes.

5. The resistor of claim 1 in which the means interconnecting adjacent pairs of resistor units comprises conductors located at opposite circumferential sides of said discontinuities, the locations of said conductors being symmetrical with respect to a diameter of said resistor, said annular insulating discs being imperforate in the region between the ends of adjacent resistor units disposed on one circumferential side of the aligned discontinuities, said insulating discs containing a hole on the other circumferential side of said discontinuities for receiving the conductor that electrically interconnects said adjacent units, the symmetrical location of said conductors enabling identical but inverted insulating discs to be used between alternate resistor units.

6. The resistor of claim 1 in which at least some of said insulating discs each comprise an annular web portion against which an edge of an adjacent ribbon is positioned and further comprise means for confining said ribbon to a position between the opposite peripheries of said disc, said confining means comprising flanges disposed at opposed peripheries of said web portion and extending longitudinally of said resistor, and means for clamping said resistor units and said insulating discs together with the flanges of said discs disposed in spaced relationship to adjacent insulating discs to afford free communication between said resistor units and the space internally and externally of the peripheries of said resistor units.

7. In the resistor of claim 5, means for clamping said resistor units and said insulating discs together comprising a series of circumferentially-spaced tension members extending longitudinally of said resistor and disposed near the outer periphery of said resistor units between adjacent segments of said ribbons, the regions of said ribbons in the vicinity of at least one of said tension members being devoid of perforations for receiving said tension member, said tension members being located at points symmetrically disposed with respect to a diametrical axis of said resistor.

8. A low inductance resistor comprising a plurality of annular resistor units, each unit comprising a conductive ribbon extending circumferentially about the unit, said ribbon having a pair of ends circumferentially-spaced apart to define an electrical discontinuity in each unit between the ends of said ribbon, each of said conductive ribbons comprising closely-spaced series-connected segments extending alternately between the outer periphery and the inner periphery of the annular unit, insulating means between the adjacent faces of said segments for requiring current traversing said ribbon at any given instance to flow in generally opposite directions through adjacent segments of each ribbon, means for mounting said annular units in superimposed collinear relationship with said regions of discontinuity being circumferentally aligned, and means electrically interconnecting said units in series circuit relationship in such a manner that at any given instant current traversing said resistor flows in opposite circumferential directions through adjacent annular resistor units, annular insulating discs disposed between adjacent resistor units in generally collinear relationship with respect to said annular resistor units to provide a solid insulating barrier between adjacent resistor units about substantially the entire circumferential extent of said resistor units, annular end caps for said resistor; and means for clamping said end caps, said resistor units, and said insulating discs together comprising tension members extending longitudinally of said resistor and disposed near the outer periphery of said resistor units between adjacent segments of the ribbons of said resistor, the regions of said ribbons in the vicinity of at least one of said tension members being devoid of perforations for receiving said tension member.

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